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PART XXXVIII

Observations on the Control of *Myriophyllum spicatum* in Kalamalka and Wood Lakes Using 2,4-D Butoxyethanol Ester in 1979 and 1980

Robert W. Adams
Michael A. Wallis
Resource Quality Section
Water Management Branch

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PREFACE

This report documents observations on the effectiveness, drift and persistence of the herbicide 2,4-D following applications to control Eurasian water milfoil in Kalamalka and Wood Lakes during 1979 and 1980. Uninterpreted data from these treatments were listed previously in Part XXX Volume I and Part XXXI Volume I and it was indicated that a discussion of results was to be published as Volume II of each report. Instead, information from the two treatment years has been combined into this new report Part XXXVIII.

1. INTRODUCTION

This report interprets 2,4-D persistence and drift data and assesses treatment effectiveness following herbicide applications made by the British Columbia Ministry of Environment to control Eurasian water milfoil (Myriophyllum spicatum L.) in Wood and Kalamalka Lakes in 1979 and 1980. A considerable effort was made by Ministry staff during 1976 through 1980 to evaluate control methods and to prevent the spread of M. spicatum in Kalamalka and Wood Lakes. Only mechanical methods (rototilling and diver dredging) were used to treat slowly expanding populations in Kalamalka Lake prior to 1978, but the cost was high and a large population in deeper water at the north end of the lake remained difficult to treat. In Wood Lake, only scattered plants were observed prior to 1978, but in that year, water transparency increased and there was a rapid expansion of M. spicatum, causing a nuisance and contributing fragments downstream to increase spread in Kalamalka Lake. Therefore in 1979 and 1980, the Ministry of Environment implemented a program combining the use of mechanical methods and the herbicide 2,4-D butoxyethanol ester (granular Aqua-Kleen formulation) in an attempt to reduce further M. spicatum growth in Kalamalka Lake and to control spread in Wood Lake. The use of 2,4-D was experimental in both these lakes, therefore the effectiveness of the treatments was examined in considerable detail, and a large number of samples were taken to monitor persistence of the herbicide in the water column and in sediments.

Herbicide residues in water at drift stations and in treatment sites were previously reported without interpretation in data reports (Goddard, 1980; Rudolph and Dyer, 1981). Some tables of sediment residue data were given in those reports, but laboratory analyses were not completed. Analysis results of all sediment samples are listed in this report (Appendix I).

2. DESCRIPITION OF TREATMENT AREAS AND MONITORING

Wood and Kalamalka Lakes (Figure 1) are uppermost of the six major lakes connected by the Okanagan River drainage system. Wood Lake, upstream of Kalamalka Lake and connected by a short man-made channel, has a surface area of 915 ha, a littoral area of 57 ha and a maximum depth of 34 m. Water quality is considered eutrophic. Kalamalka Lake is larger, with a surface area of 2568 ha, littoral area of 152 ha and a maximum depth of 142 m. Kalamalka Lake is considered to be oligotrophic (Anon., 1974). In 1978, about 12 ha of M. spicatum were mapped in each of Kalamalka and Wood Lakes; in most of these areas the plant density was sparse but had increased over the previous few years.

Herbicide treatments (listed in Table 1) were referred to as spot treatments (<0.4 ha) or block treatments (>0.4 ha) due to the difference in anticipated herbicide drift. In 1979, ten spot treatments totalling 1.42 ha and one 11.5 ha block treatment were made in Kalamalka Lake. Three spot treatments totalling 0.7 ha and one block treatment of 5.9 ha were made in Wood Lake in 1979. In 1980, 18 spot treatments totalling 3.16 ha were made in Kalamalka Lake and two block treatments totalling 18.5 ha were made in Wood Lake. Application rates were 22 kg 2,4-D active ingredient (a.i.)/ha where the water depth was less than 2.5 m and the cover of weeds less than 70 percent or 45 kg 2,4-D a.i./ha in deeper water or where weed cover was greater than 70 percent. Herbicide application methods and herbicide residue monitoring were previously described by Goddard (1980) and Rudolph and Dyer (1981).

Over 850 water samples were collected in treatment areas to monitor herbicide persistence and over 600 water samples were collected at selected distances outside these treatment areas to document 2,4-D drift. Water samples were usually analyzed for 2,4-D acid, due to the rapid hydrolysis of the 2,4-D butoxyethanol ester (BEE) to acid at temperatures between 17-22°C and pH levels of 8.2-8.7 in these lakes (Bothwell and Daley, 1981).

However, some samples were analyzed for 2,4-D BEE, 2,4-D acid, and its breakdown product, 2-4-dichlorophenol (2,4-DCP). Sediment samples were taken to document 2,4-D persistence in sediment at selected sites. Treatment areas, water and sediment sample sites are shown in Figures 2-8.

Qualitative observations were made on 2,4-D effectiveness by comparison of plant cover and growth vigour (abundance of new stems and branches) before and after treatment in treated and untreated areas. The area and density of M. spicatum populations mapped in 1978, 1979 and 1981 also was compared (Appendix II) to document treatment effectiveness.

3. MONITORING RESULTS BY TREATMENT SITE

3.1 KALAMALKA LAKE - NORTH END; 1979

This area contained the largest population of M. spicatum in Kalamalka Lake and a large block treatment (11.5 ha) was made near "Kal" public beach on June 14, 1979 (Figure 2). Three monitoring stations were established in the treatment area and water sampling commenced here five days after the application. Water borne 2,4-D acid concentrations declined from 0.038 mg/L on day 5 to non-detectable levels (<0.001 mg/L) 26 days after the application.

Drift of 2,4-D was monitored at nine stations located between 1000 and 4200 m from the treatment area. Herbicide was detected only at the 1000 m stations at a maximum concentration of 0.018 mg/L on the first and second day after treatment.

On June 29, 1979, two spot applications totalling 0.4 ha also were made in the north end of kalamalka Lake to small populations left untreated on each side of the major block treatment made earlier. Samples taken in each spot application site indicated that 2,4-D residues persisted until levels in the large treatment block became non-detectable.

The overall effectiveness of block and spot treatments was calculated (method described in Appendix II) to have resulted in an 86 percent decline in M. spicatum abundance between August, 1978 and October, 1979. At the end of the 1979 growing season, only scattered M. spicatum were observed to have survived the block treatment but effectiveness was poor in the spot treatment adjacent to the outlet of Coldstream Creek and the population here continued to expand in size during the fall of 1979.

In the summer of 1980, intensive diver dredging was implemented to remove the remaining plants at the north end of Kalamalka Lake. The degree

of long-term control achieved in the main block herbicide treatment area could not be determined as the dredge crews removed most new growth. As diver dredging cannot be used unless plants are sparse, it was interpreted that the herbicide treatment was effective in preventing growth to nuisance levels in 1980. However, in the spot treatment area at the mouth of Coldstream Creek, a dense population developed in 1980 which could not be dredged and a second attempt at herbicide control was made in that year (Section 3.5).

3.2 KALAMALKA LAKE - COSENS BAY; 1979

Spot treatments were made on three occasions in the Cosens Bay area of Kalamalka Lake (Figure 3). Two treatments about 100 m apart, totalling 0.4 ha were made on July 7, 1979. Waterborne 2,4-D residues were sampled commencing on day 5 and declined from a maximum of 0.03 mg/L to non-detectable levels after 43 days. Although concentrations were low, the long persistence was unusual for a spot treatment and implies either that there was very little water movement in the bay or that the sample sites were affected by two spot treatments made on August 1, 1979 (totalling 0.2 ha), which were only about 100 m away. Herbicide persisted for 28 days following these August treatments. Three additional spot treatments were made on September 12, 1979 (totalling 0.2 ha) and waterborne residues persisted for 12 days at concentrations between 0.01 and 0.001 mg/L.

Effectiveness of the spot applications was variable. In October 1979 no M. spicatum was observed in three sites but expansion had taken place in five other sites. It was calculated that there was only a 20 percent reduction in plant abundance in the treatment sites, however, new growth was observed in several new sites and control in the whole area was judged to be poor. Additional treatments were made in 1980 and these are discussed in Section 3.6.

3.3 KALAMALKA LAKE - WALSHE'S POND; 1979

Walshe's Pond is a 0.27 ha lagoon with a maximum depth of 1.5 m on the southwest side of Kalamalka Lake and is completely enclosed with no opening to the lake (Figure 4). The 0.2 ha of dense M. spicatum in the pond was treated with 2,4-D on August 1, 1979. Sampling of waterborne herbicide residues commenced on day 12 after application and declined from a maximum of 1.22 mg/L to 0.034 mg/L when sampling was terminated 77 days after the application.

A comparison of pre- and post-treatment plant populations showed a high treatment effectiveness. There was no indication that any M. spicatum survived this treatment when the area was surveyed October, 1979. Follow-up observations were made in the summer of 1981. M. spicatum was present but only scattered plants were observed throughout the pond. Thus nuisance growth was eliminated for the remainder of the treatment growing season and at least two subsequent growing seasons.

3.4 WOOD LAKE - SOUTH END; 1979

Block treatments totalling 5.9 ha were made in the southeast and southwest corners of Wood Lake on June 8, 1979 (Figure 5). Four sample stations were established in the treatment areas. Sampling of the water column in the treated areas commenced nine days after treatment and 2,4-D concentrations declined from a maximum of 0.027 mg/L to non-detectable levels 18 days after treatment at three sample sites. At one station in an embayment in the southwest corner of the lake, 2,4-D persisted at low levels (0.001-0.004 mg/L) for a total of 107 days. The decline to non-detectable levels in this embayment coincided with a change in wind from a light/moderate southeasterly to a moderate southwesterly.

Fifteen drift stations were located at distances from 500 to 6000 m from the treatment area. Waterborne 2,4-D residues were detected at a maximum concentration of 0.025 mg/L at 2000 m three days after the

application. Stations at 3000 m, 3800 m, 5500 and 6000 m (at the north end of the lake) were added after detection at 2000 m and were sampled on days 4, 5 and 6 after treatment. No herbicide was detected at these stations or at the 2000 m or 500 m stations after day 3. During this monitoring period a moderate wind blew from the south and it is likely that surface waters containing 2,4-D moved rapidly northward during the first three days after treatment. By the fourth day it appeared that residues in surface waters further than 500 m north of the treatment area had dissipated to non-detectable levels.

The persistence of 2,4-D in sediments was monitored in conjunction with the block treatment at the south end of Wood Lake (data are listed in Appendix Table 1). Two control stations located 500 m north of the treatment area and two stations located directly in the treatment area, were sampled between 6 and 113 days after the application. A total of 16 sediment samples were taken on seven occasions from outside the treatment area and none contained detectable (>0.005 µg/g) levels. Two replicate samples were taken at each treatment station and showed high variability in herbicide residues. The maxium 2,4-D level observed in sediments was 1.610 µg/g. No residues were detected after 282 days.

Three spot treatments totalling 0.7 ha were made at the south end of Wood Lake on June 21, 1979. Water samples were taken from each site commencing two days after treatment. 2,4-D was detected in water samples from only one area, declining from 0.012 mg/L to non-detectable levels by 19 days after treatment.

The effectiveness of the 1979 Wood Lake treatments was documented from field observations on a number of occasions between 1978 and mid-1980. In the season prior to the 2,4-D application, the south end of Wood Lake had been thoroughly treated by a diver-dredge operation which left only sparse plants. However, rapid regrowth and reinvasion of the area occurred in the fall of 1978 and spring of 1979 which required the June, 1979 herbicide treatments. Observations two weeks after the June, 1979 application

indicated that M. spicatum populations in the southwest corner showed more symptoms of poisoning than in the southeast corner. About 50 days after the treatment, no M. spicatum top growth could be found in the southwest corner, while plants in the southeast corner showed signs of 2,4-D poisoning but also development of new shoots. Observations made 2, 4 and 12 months after treatment confirmed this difference in treatment success between the two areas. A comparison of weed distribution maps prepared in September, 1978 with maps prepared in October, 1979 indicated a 70 percent reduction in M. spicatum abundance in the west weed bed and a 450 percent expansion in the east weed bed. This result is consistent with the longer persistence of 2,4-D residue in the water column in the southwest corner of the lake (107 days) compared to the southeast corner (18 days). Although herbicide in the sediment was detected longer in the southeast corner, sample variability was too high for this result to be significant.

3.5 KALAMALKA LAKE - NORTH END; 1980

In 1980, only spot treatments were made in Kalamalka Lake. Two of these applications, located about 150 m apart and totalling 1.0 ha, were made near the outlet of Coldstream Creek on September 9, 1980 (Figure 6). A water sample station was established in each site and sampling of 2,4-D BEE, 2,4-D acid and 2,4-DCP commenced the day of application. A maximum 2,4-D BEE concentration of 0.033 mg/L was recorded on day 5. Concentrations of 2,4-D acid declined from a maximum of 0.035 mg/L to non-detectable levels on day 9, except for a single reading of 0.0019 mg/L on day 13. No further samples were taken. No 2,4-DCP was detected. Drift was monitored at four stations (92-95 on Figure 6) located about 200, 300, 400 and 600 m from the nearest treatment site. Herbicide was detected at a low concentration (0.0026 mg/L) in one sample, 400 m toward the lake outlet on day 2.

Field observations in April, 1981, seven months after treatment, indicated that plant mortality was low in both spot treatments. Top growth of M. spicatum appeared to be thinned considerably in some of the treatment areas, but new shoots were observed growing from many root crowns which

apparently were not killed by the herbicide. It also appeared that the herbicide should have been applied to a larger area to treat the entire M. spicatum population in this site. Comparison of vegetation maps prepared from surveys in October, 1981 with those made in October, 1979, indicated a tenfold increase in cover of M. spicatum in this area, one year after treatment. This poor treatment effectiveness was attributed to the flushing effect of Coldstream Creek outflow and possibly groundwater movement which likely diluted herbicide applied in this site.

3.6 KALAMALKA LAKE - COSENS BAY; 1980

In 1980, spot treatments were made for the second time in Cosens Bay. Six applications totalling 0.5 ha were made along a 1500 m stretch of shoreline on June 26, 1980. Water samples in the treatment areas were collected at four stations commencing on the day of treatment and analyzed for 2,4-D BEE, 2,4-D acid and 2,4-DCP. A maximum concentration of 0.026 mg/L 2,4-D BEE was recorded on the day of treatment; no detectable levels of 2,4-D BEE were recorded after post-treatment day 4. Residues of 2,4-D acid declined from a maximum of 0.023 mg/L on post-treatment day 4 to non-detectable levels after 32 days. No 2,4-DCP was detected in any samples.

Two drift stations (54, 55 on Figure 6) were located about 100 and 450 m from the treatment sites. Residues were detected at both stations on some days during a 20 day period after treatment, but at close to non-detectable levels.

Sediment samples were collected two days before application and 36 days and 57 days after application in four treatment areas and at one site outside treatment areas (Appendix I, Table 2). The 2,4-D residue concentrations were highly variable. A maximum concentration of 1.39 µg/g was recorded at one treatment site station on day 36; the maximum on day 57 was 0.35 µg/g. A concentration of 0.013 µg/g was recorded from a sample outside the treatment site.

These treatments were considered to have been moderately effective in reducing nuisance M. spicatum populations. Field observations 26 days after application showed that most top growth was killed. At the end of the following growing season (1981), there was approximately 60 percent less M. spicatum in the treatment plots. However, new colonies developed around and between the treated areas and fragments from these populations no doubt increased the rate of regrowth in the treatment areas.

3.7 KALAMALKA LAKE - LISHEEN ESTATES; 1980

Four spot treatments totalling 0.2 ha were made on July 30, 1980 along 1100 m of shoreline adjacent to Lisheen Estates (Figure 6). One water sampling station was established in each treatment area, and sampling commenced on the day of application. Waterborne 2,4-D residues declined from a maximum of 0.016 mg/L to non-detectable levels approximately 14 days after application. Drift residues were monitored at five stations established at distances from 100-600 m from the nearest treatment site. Residues were recorded only at the 100 m station and at low concentrations (<0.002 mg/L).

2,4-D residues were sampled in sediments on one occasion (13 days after application) at four stations. The concentrations in these samples ranged from 0.008 to 0.08 µg/g (Appendix I, Table 3).

Field observations indicated that these spot applications were effective in reducing M. spicatum growth in treatment areas, but not in suppressing colonization of adjacent areas. M. spicatum within the treatment sites declined by approximately 75 percent between October, 1979 and October, 1981, with some sites almost entirely devoid of the plant. But the total area occupied by M. spicatum in the immediate vicinity of the applications increased by approximately 80 percent between 1979 and 1981, most of it at a low density (< 40 percent M. spicatum cover). Thus, new colonization occurred just a few metres away from treatment locations where most of the previously existing plants were killed.

3.8 KALAMALKA LAKE - SOUTH END; 1980

M. spicatum populations were observed to be expanding in a number of small colonies at the south end of Kalamalka Lake in 1979. Six spot treatments covering a total of 1.5 ha were made in this area on September 25, 1980 (Figure 7). Three insite water residue stations were sampled commencing the fourth day after treatment. Waterborne 2,4-D residues declined from a maximum of 0.31 mg/L to non-detectable levels in 28 days. The maximum concentrations were observed in a treatment located in a small embayment (Station 39) where water movement was likely restricted. Herbicide drift was sampled at seven drift stations located at distances of 1100 and 2100 m from the treatment areas. Barely detectable residues were recorded in the first set of samples at 1100 m on day 4 after treatment and no detectable levels were recorded on day 7 or subsequent sample dates. It was unlikely for residues to be detected over 1000 m from spot treatments and it was suspected that the source of this drift was from the 8.5 ha treatment at the north end of Wood Lake, near the Oyama Canal outlet into Kalamalka Lake. This Wood Lake treatment was made on September 27, two days before herbicide was detected at the 1100 m stations in Kalamalka Lake (see Section 3.10). Drift in Kalamalka Lake from this source was shortlived however, as no herbicide drift was detected after day 4.

Two sediment samples were taken for 2,4-D residue analysis in one spot treatment site at the south end of Kalamalka Lake, 53 days after treatment. 2,4-D acid concentrations of 0.036 and 0.068 µg/g were recorded and no detectable levels of 2,4-D BEE were found (Appendix I, Table 4).

Surveys of M. spicatum at the south end of Kalamalka Lake in 1979 indicated that the plant was widely distributed, but sparse in most areas. The Oyama Canal was the only site where dense populations were observed. Because sparse M. spicatum covered extensive areas and were mixed with other plant species, it was difficult to diver-dredge; hence, herbicide was used in an attempt to eliminate the scattered plants and prevent growth of nuisance densities. Comparison of M. spicatum distribution maps for 1979

and 1981 indicated that the herbicide treatment was effective in reducing the density of M. spicatum in the Oyama Canal to scattered plants. In the other spot treatment sites where M. spicatum was sparse before treatment, populations remained sparse but in some locations, the area covered by these sparse populations increased. In particular the M. spicatum weed beds around the mouth of the Oyama Creek increased in area by over 300 percent, one year after treatment.

3.9 WOOD LAKE - SOUTH END; 1980

A block of 10 ha was treated at the south end of Wood Lake on September 10, 1980 (Figure 8). Water borne concentrations of 2,4-D BEE, 2,4-D acid and 2,4-DCP were measured at four sites in the treatment area (1, 3 and 5 hours after treatment, then at longer intervals over a 58 day period). 2,4-D BEE concentrations declined from a maximum of 1.38 mg/L, three hours after treatment to non-detectable levels after four days. 2,4-D acid levels in the treatment area declined from a maximum of 0.62 mg/L, one day after treatment to non-detectable levels after 50 days. A maximum concentration of 0.014 mg/L 2,4-DCP was sampled five hours after treatment and no detectable levels were recorded when sampled on days 1 and 4 after treatment.

Herbicide drift was measured at 22 stations located from 500 to 6000 m from the treatment site. Only on one occasion was a herbicide level in excess of 0.01 mg/L observed at any drift stations (Station 09). Lower residue concentrations were detected at the north end of the lake, 6000 m from the block treatment. It appeared that most of the 915 ha lake epilimnion had detectable herbicide residues at concentrations between 0.001 and 0.003 mg/L just prior to the 8.5 ha treatment at the north end of Wood Lake on September 27, 1980.

The presence of 2,4-D in sediments was monitored immediately before the application and 70 and 197 days after treatment. No herbicide was detected in pre-treatment samples. Sediment borne 2,4-D BEE concentrations averaged

0.012 µg/g (n=4) and 2,4-D acid concentrations averaged 0.58 µg/g (n=8) 70 days after treatment. Only 2,4-D acid was sampled on day 197 and concentrations averaged 0.27 µg/g (n=6) (Appendix I, Table 5).

Comparison of vegetation maps prepared in 1979 and 1981 indicated that spicatum populations had expanded about seven percent one year after treatment. There was a reduction in the density of some populations in shallow water, but deeper populations along the drop off in 6 m of water, remained dense in 1981. The density of populations in the southeast corner of Wood Lake treated in 1979, and not treated in 1980, increased dramatically in 1981. Thus the 1980 applications were not effective in reducting M. spicatum abundance below pre-treatment levels, but it is likely these treatments presented a much larger expansion in population size in 1981 had there been no treatment.

3.10 WOOD LAKE - NORTH END; 1980

An 8.5 ha block treatment was made on September 27, 1980 in a strip which extended along the northwest shore and north shore of Wood Lake (Figure 8), 17 days after the 10 ha treatment at the south end of the lake. Waterborne 2,4-D acid residues were sampled at four stations in the treated areas commencing on day 5 after treatment. Residues declined from a maximum of 0.015 mg/L to non-detectable levels after 33 days.

Herbicide drift was sampled at five locations at distances between 500-1800 m from the treatment site along the length of Wood Lake. Just prior to the north end treatment, 2,4-D was present at low levels (mean of 0.0019 mg/L on September 22, 1980) throughout much of the epilimnion of the lake, due to the 8.5 ha treatment at the south end. These concentrations were increased to a mean of 0.005 mg/L at drift stations along the length of the lake for 30 days after the north end treatment. The return to non-detectable levels (<0.001 mg/L) on day 33 probably resulted from the mixing of the water column during the annual breakdown of the thermocline following a windy period extending over several days.

The concentrations of 2,4-D in the sediments were sampled 53 and 180 days after treatment. On day 53, concentrations of 2,4-D acid averaged 0.03 µg/g (n=4) and 2,4-D BEE averaged 0.033 µg/g (n=4). On day 180 only 2,4-D acid was measured and concentrations averaged 0.253 µg/g (n=6). No explanation can be made for the higher 2,4-D acid concentrations on the latter sample date (Appendix I, Table 6).

This application was moderately effective in reducing existing M. spicatum populations with an overall decline in abundance of approximately 35 percent observed one year after treatment. A relatively greater degree of control was achieved along the north end of Wood Lake than along the northwest shoreline. Along the north end there was a small reduction in the area of M. spicatum and a substantial decrease in the density of M. spicatum populations in 1981, compared with pre-treatment observations in 1979. In the northeast corner of the lake there were five M. spicatum weed beds which could not be treated due to limitations of the herbicide use permit. The density of three of these weed beds increased considerably between 1979 and 1981.

The M. spicatum infestation along the northwest side of Wood Lake was too large to treat entirely with herbicide in 1980 because of the limitations in the pesticide use permit which specified treatment of no more than 10 ha along the north and northwest shoreline to treat as many dense populations as possible. 2,4-D was applied to a 10 m wide strip in shallow water along about 3500 m of shore. Deeper populations along the drop-off (5-6 m deep) were not treated where the littoral zone was over 10 m wide. A comparison of vegetation maps prepared before and after treatment indicated that the dense surfacing populations close to shore in 1979 had been reduced to sparse, non-surfacing plants, in 1981. A total of 54 separate populations were located in this area; 30 decreased in density, 9 increased and 15 remained unchanged. Along the deeper parts of five sites, where the littoral was wider than the treatment swath, dense populations of M.

spicatum were observed in 1981. Although plant density was reduced near shore, the total area covered by these populations expanded by over 75 percent in 1981. The deeper populations provided a large source of fragments and lateral shoots for re-infestation.

4. SUMMARY AND CONCLUSIONS

The granular formulation of the herbicide 2,4-D butoxyethanol ester was applied as part of an integrated mechanical/chemical program to control Eurasian water milfoil in Wood and Kalamalka Lakes in 1979 and 1980. The effectiveness and herbicide dispersal resulting from four large block treatments, ranging from 5.9-11.5 ha, and 31 spot treatments, < 0.4 ha, were monitored.

In water samples from three treatment sites, the persistence of 2,4-D BEE was compared to 2,4-D acid and its breakdown product 2,4-DCP. Maximum concentrations of 2,4-D BEE were recorded on the treatment day and declined to non-detectable levels within seven days. 2,4-DCP was recorded only on the treatment day and at low levels (<0.01 mg/L). 2,4-D acid persisted longest and was sampled most intensively. Concentrations of 2,4-D acid at each treatment site are summarized in Table 2.

Following the large treatments, maximum 2,4-D acid concentrations in the water column were less than 0.05 mg/L within five days. The herbicide persisted at concentrations greater than 0.01 mg/L for 20-47 days and at concentrations greater than 0.001 mg/L for 25-107 days. Longer persistence was associated with little water mixing to cause herbicide dispersion. Following spot treatments, the maximum herbicide concentrations detected in water samples were 0.01-0.03 mg/L within 4-8 days. The herbicide was detected at concentrations over 0.001 mg/L for periods of up to 43 days. A number of spot treatment samples were likely contaminated by drift from the larger treatments.

Concentrations of 2,4-D acid at drift stations are summarized in Table 3. Drift stations were established 500-6000 m from the large treatment sites. No herbicide was detected at concentrations greater than 0.1 mg/L in these water samples. Herbicide was detected at concentrations just over 0.01 mg/L at distances up to 2000 m within 3 days of treatment. In Wood

Lake, where treatments of 8.5 and 10.0 ha were made 17 days apart, concentrations between 0.001 and 0.01 mg/L were recorded throughout the epilimnion of the lake until fall turnover (about 32 days after treatments). Drift stations were established at 100-2100 m from spot treatment sites. No herbicide was detected at concentrations greater than 0.01 mg/L. Concentrations just above 0.001 mg/L typically were detected about 500 m from these treatment sites except where drift from adjacent large treatments likely contaminated samples. The persistence of herbicide at drift stations at these barely detectable levels varied considerably from 2 to 20 days.

Persistence of 2,4-D in the sediment was monitored in Wood Lake during 1979 and in both Wood and Kalamalka Lakes during 1980. The maximum residue found was 1.61 µg/g, 17 days after treatment at the south end of Wood Lake in 1979. In general, sample concentrations of 2,4-D in the sediment appeared to be at maximum levels about 20 days after application and declined on successive sample dates. Typical maximum sample concentrations were in the range of 0.2-0.5 µg/g. Sediment residues were not detected outside treatment areas with one exception which may have been an analysis error.

The maximum 2,4-D concentrations in sediment sampled from Kalamalka Lake and Wood Lakes during 1979 and 1980 were considerably less than those observed in post-treatment samples taken from Okanagan Lake in 1977 and 1978 (Anon., 1980). It appears likely that this difference is due to a change in the method of handling samples; sediment cores were frozen in 1977/78 and were air-dried in 1979/80. In addition, cores were deeper in 1979/80 (10-15 cm) compared to 1977/78 cores (≈5 cm). Some loss of herbicide might have resulted from volatilization or degradation of residues or loss of some interstitial water (containing most of the herbicides) during handling of air-drying samples. As herbicide concentrations were found to decrease in sediment with depth (Anon., 1980), deeper cores would result in lower sample concentrations.

Effectiveness of the various treatments in reducing cover of M. spicatum is summarized in Table 4. Treatment effectiveness varied greatly between the 10 application sites discussed. Estimated removal rates varied from a tenfold expansion near Coldstream Creek in the worst case to nearly 100 percent removal in the best case in Walshe's pond. In the worst case, creek outflow near the application site likely diluted 2,4-D concentrations rapidly before M. spicatum plants were affected. Generally treatment of dense populations in open lake situations reduced plant abundance to sparse levels, eliminating nuisance growth for at least one year following treatment. Where sparse populations were treated to prevent development of nuisance populations, there was usually no increase in density, although in some cases the size of these sparse beds increased in area. Spot treatments were unsuccessful in preventing spread of sparse populations in many sites probably because nearby plants remained as a source of reinfestation. In order to prevent spread, herbicide treatments must be made to nearly all viable plants to eliminate regrowth from fragments. In the case of Wood Lake, M. spicatum expanded at an unexpectedly rapid rate and herbicide permits were too limited in size to treat all populations. In Kalamalka Lake, some spot treatments were too small and missed scattered plants. In both lakes there were some locations where little mortality resulted from herbicide treatments, likely due to the rapid dilution of 2,4-D in the water column (creek inflow) or in sediments (groundwater upwelling). Thus the main benefit of 2,4-D use in these lakes was the elimination of dense M. spicatum populations which prevented their fragmentation and rapid spread for at least one year following treatment.

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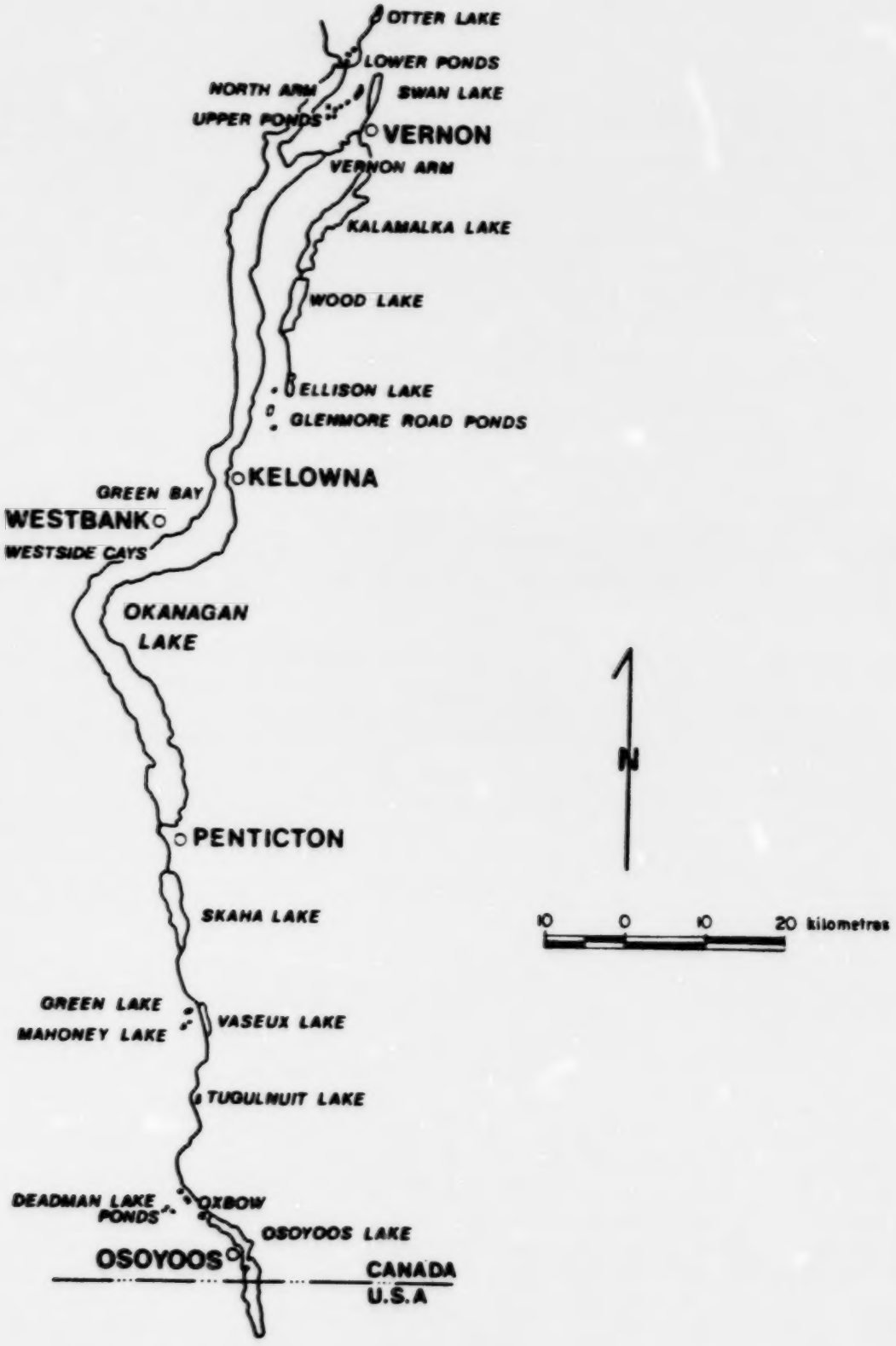
Figure 1. Mainstem lakes of the Okanagan Valley



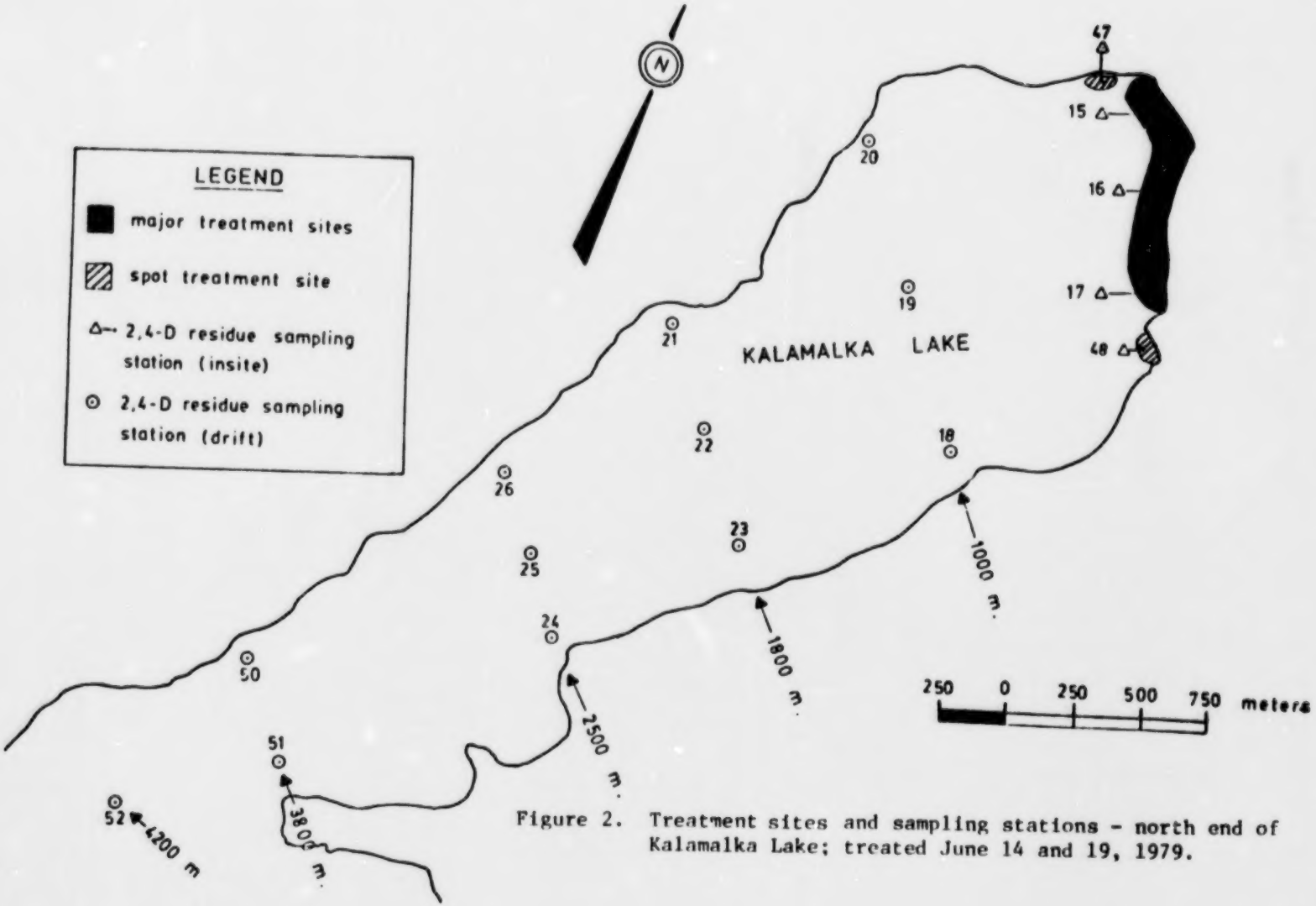


Figure 2. Treatment sites and sampling stations - north end of Kalamalka Lake; treated June 14 and 19, 1979.

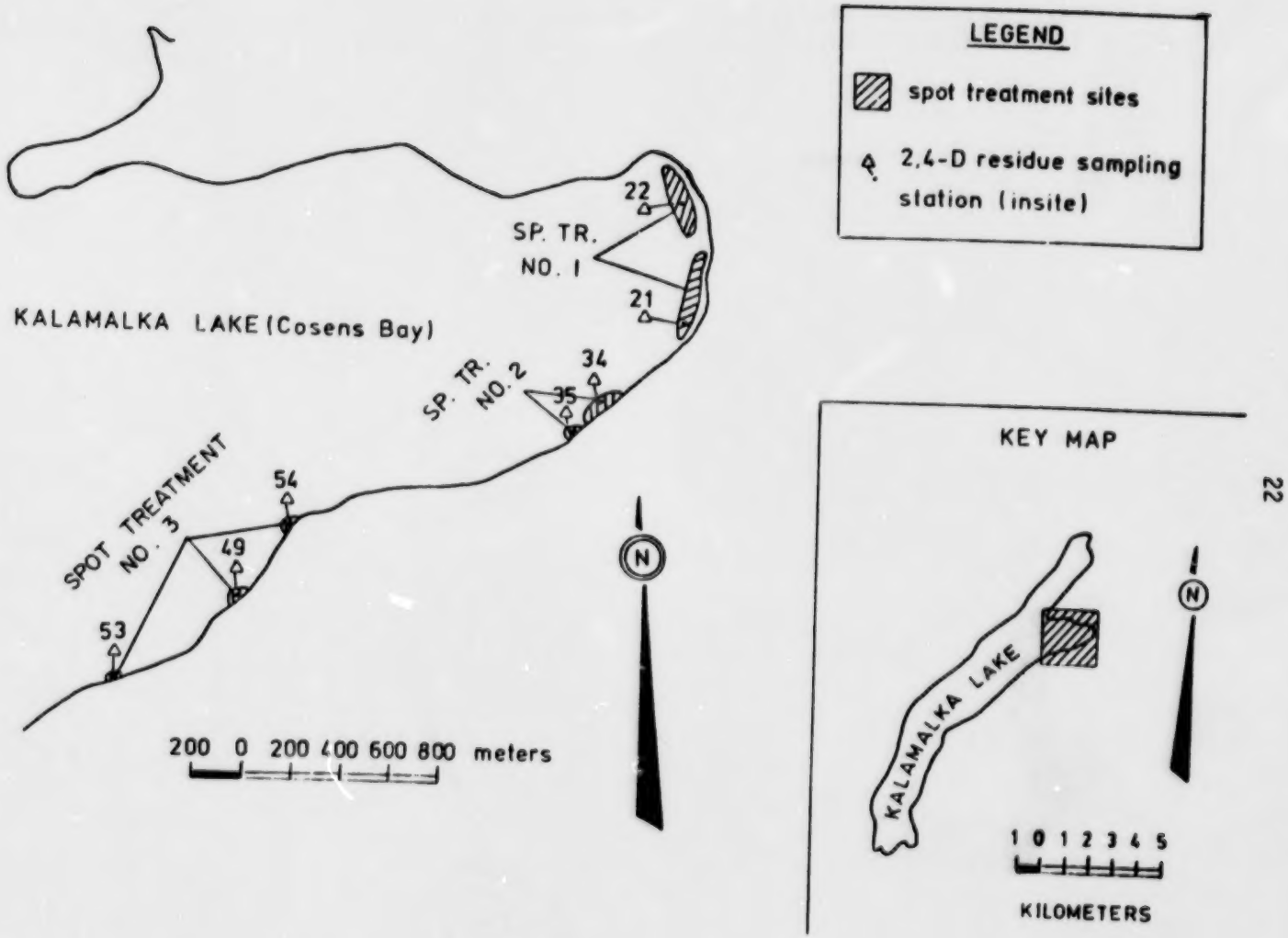
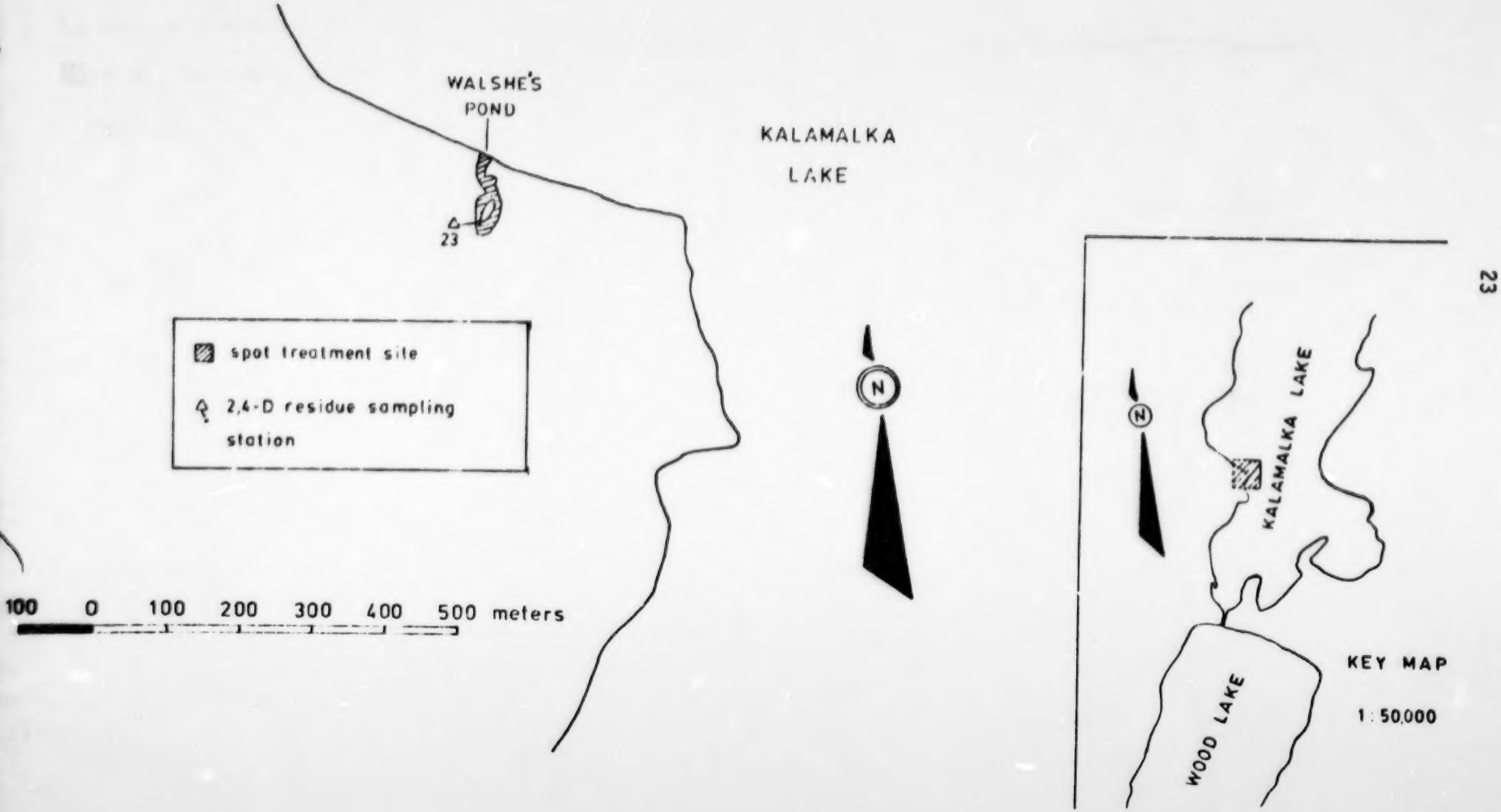


Figure 3. Spot treatment sites and sampling stations - Cosens Bay; treated July 7 (No. 1); August 1 (No. 2) and September 12, 1979 (No. 3).

Figure 4. Location of Walshe's pond treated on August 1, 1979.



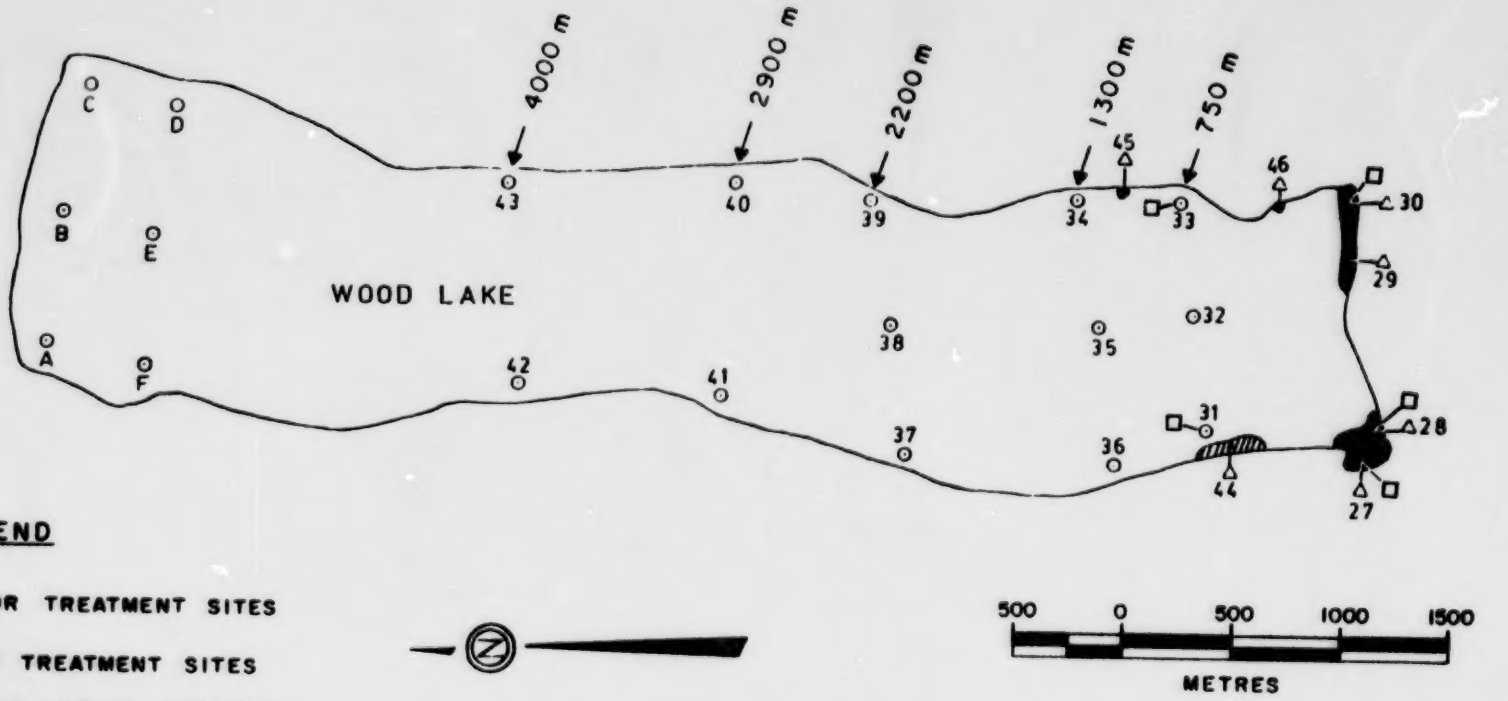


Figure 5. Treatment sites and sampling stations - south end of Wood Lake treated on June 7, 1979 (major treatments) and June 21, 1979 (spot treatments).

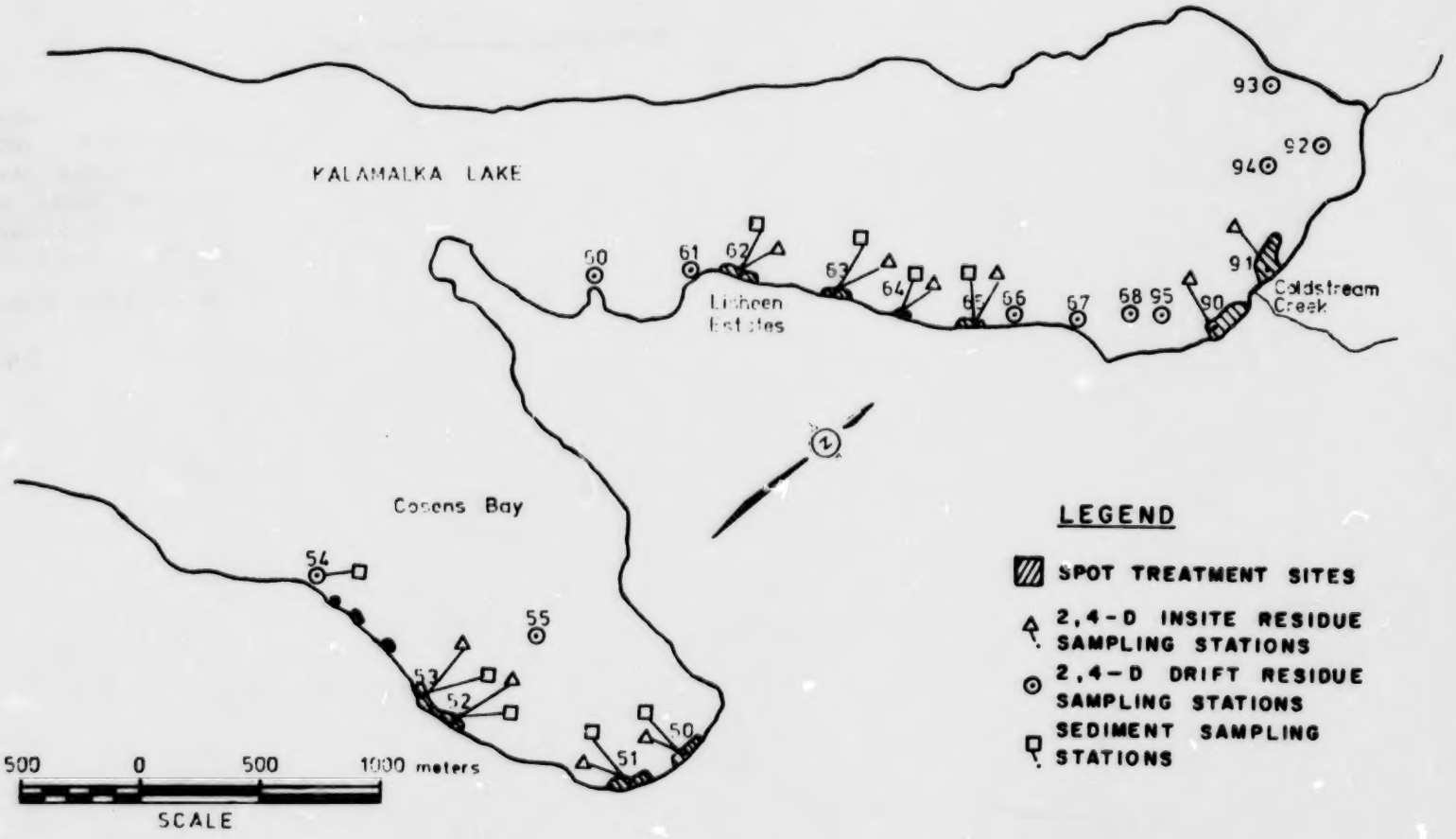


Figure 6. Spot treatment sites and sampling stations at the north end of Kalamalka Lake treated on June 26 (Cosens Bay), July 30 (Lisheen Estates) and September 9, 1980 (Coldstream Creek).

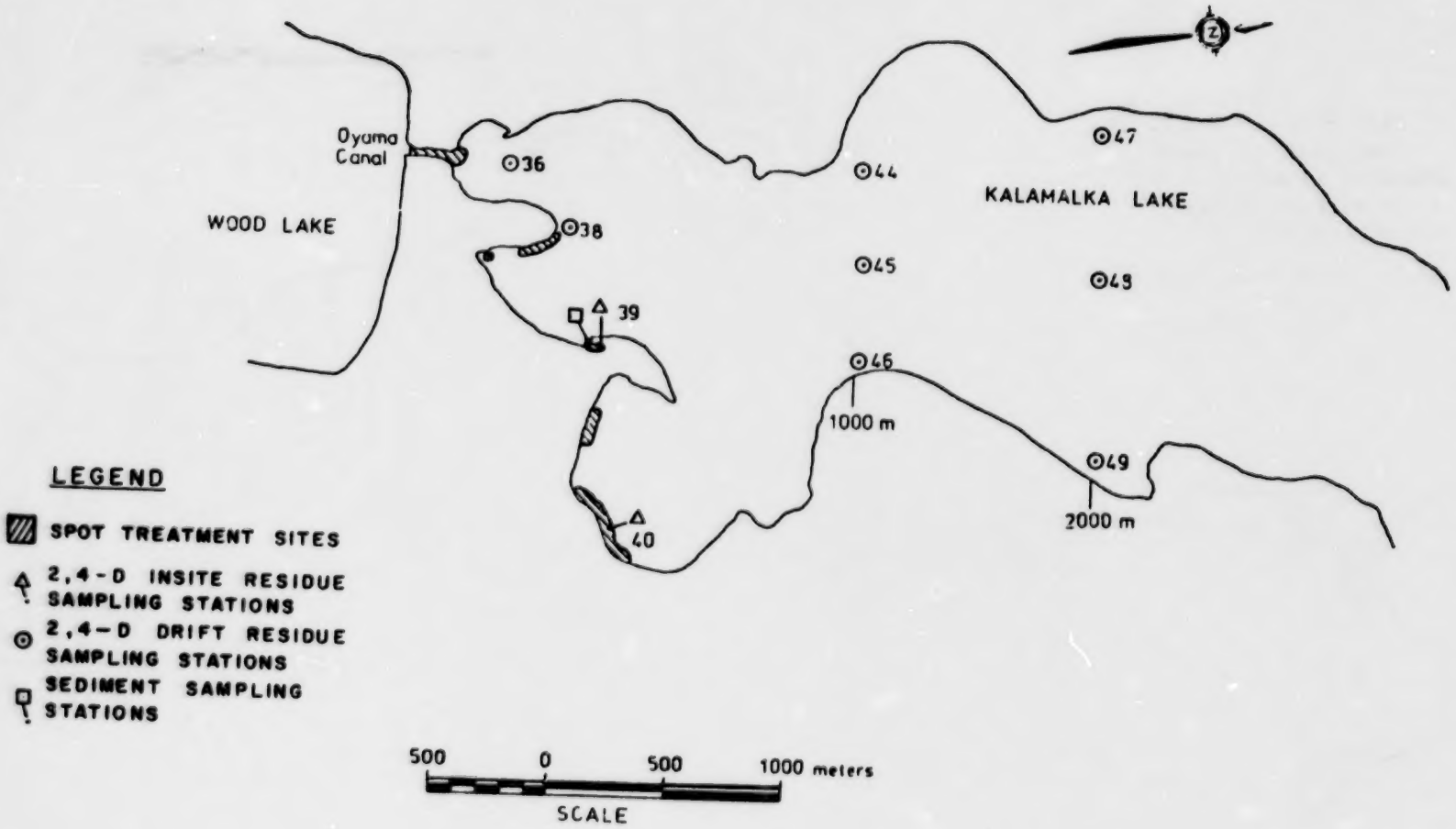


Figure 7. Spot treatment sites and sampling stations at the south end of Kalamalka Lake treated on September 25, 1980.

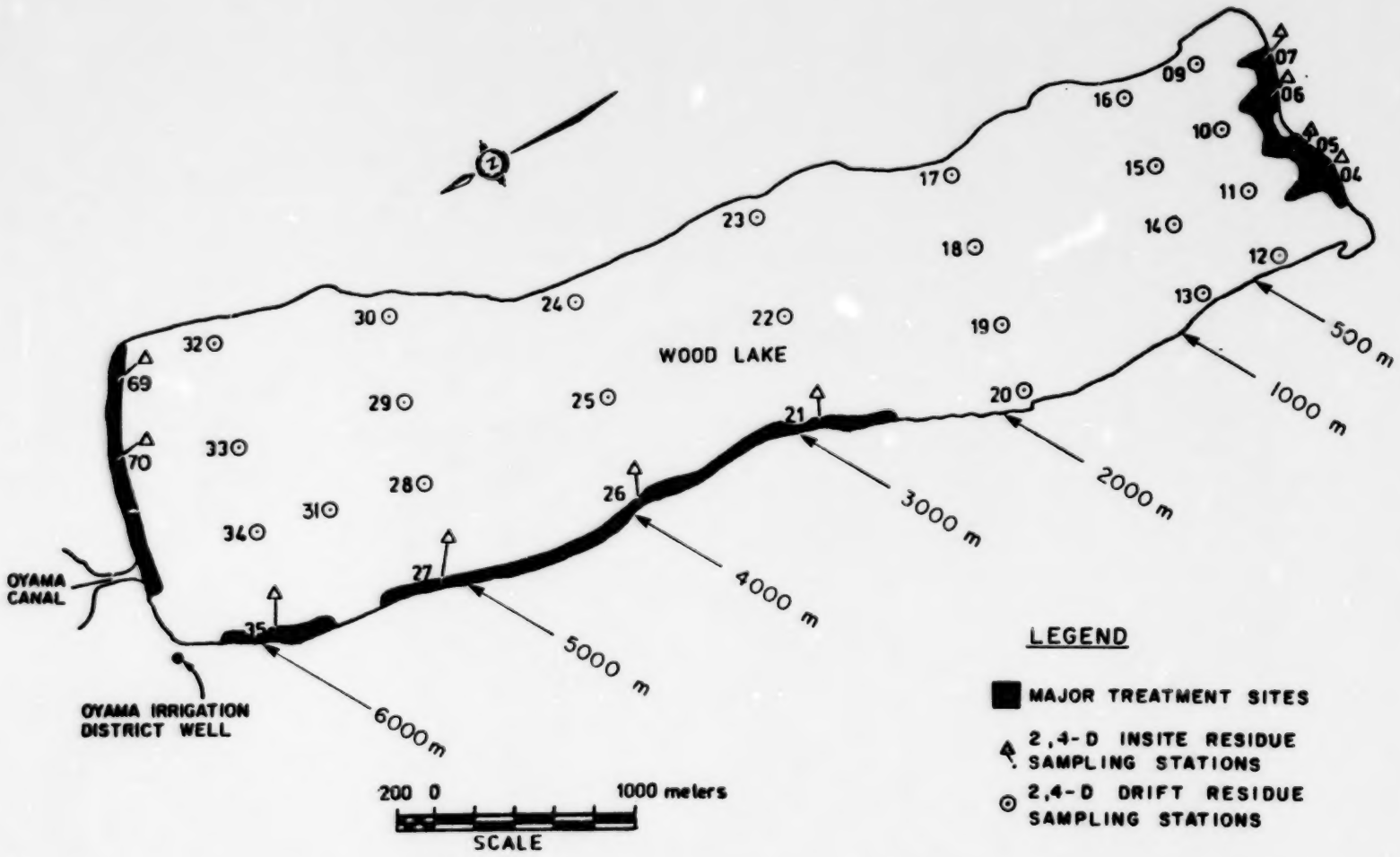


Figure 8. Treatment areas and sampling stations in Wood Lake treated on September 10, 1980 (south end) and September 27, 1980 (north end).

TABLE 1
LIST OF HERBICIDE TREATMENTS: 1979, 1980

Location	Application Date	Treatment Rate (kg a.i./ha)	Treatment Size (ha)
A. 1979			
N. End Kalamalka Lake	14/06/79	22/45	11.5
	21/06/79	22/45	0.42 (2 sites)
Cosens Bay, Kalamalka Lake	11/07/79	45	0.4 (2 sites)
	01/08/79	45	0.2 (2 sites)
	12/09/79	45	0.2 (3 sites)
Walshe's Pond, Kalmalka Lake	01/08/79	22	0.2
S. End Wood Lake	08/06/79	22/45	5.9
	21/06/79	45	0.7 (3 sites)
		Total	18.52
B. 1980			
N. End Kalamalka Lake	09/09/80	45	1.0 (2 sites)
Cosens Bay, Kalamalka Lake	11/07/80	45	0.4 (6 sites)
Lisheen Estates, Kalamalka Lake	30/07/80	45	0.2 (4 sites)
S. End Kalamalka Lake	25/09/80	45	1.56 (6 sites)
S. End Wood Lake	10/09/80	45	10.0
N. End Wood Lake	27/09/80	45	8.5
		Total	21.66

TABLE 2
PERSISTENCE OF 2,4-D ACID IN TREATMENT AREAS FOLLOWING HERBICIDE APPLICATIONS, 1979-1980

Location	Application Date	Treatment Size (ha)[1]	Treatment Rate (kg a.i./ha)	No. Sampling Stations & (No. Samples)	Maximum[2] 2,4-D Conc.	Persistence in Days[3] per Conc. in mg/l >0.1	>0.05	>0.01	>0.005	>0.001	Comments
A. Treatments smaller than 1 ha in open water, listed by treatment date											
S. End Wood Lake	21/06/79	0.50	45	1 (7)	ND	-	-	-	-	-	First sampled 3 days after treatment; suspect last station affected by drift from 5.9 ha treatment 450 m to south on 05/06/79
	21/06/79	0.10	45	1 (7)	ND	-	-	-	-	-	
	21/06/79	0.10	45	1 (14)	0.012	ND	ND	8-11	11	18	
N. End Kalamalka Lake	21/06/79	0.21	22	1 (18)	0.020	ND	ND	8-11	18	18	First sampled 3 days after treatment; suspect stations affected by drift from 12 ha treatment 80 m away on 04/06/79
	21/06/79	0.21	45	1 (19)	0.029	ND	ND	6	8	18	
Cosens Bay, Kalamalka Lake	11/07/79	0.4 (2 sites)	45	2 (92)	0.030	ND	ND	8-13[4]	43-45	43-45	Sites 100 m apart; first sampled 5 days after treatment
	01/08/79	0.2 (2 sites)	45	2 (40)	0.006	ND	ND	ND	15-19	28	Sites 25 m apart; first sampled 12 days after treatment
	12/09/79	0.2 (3 sites)	45	3 (30)	0.007	ND	ND	ND	8-12	12	Sites 300 m apart; first sampled 7 days after treatment
Cosens Bay, Kalamalka Lake	26/06/80	0.5 (6 sites)	45	4 (190)	0.023	ND	ND	4-6[5]	17	32	6 sites along 1500 m shoreline
Coldstream Ck., Kalamalka Lake	09/09/80	1.0 (2 sites)	45	2 (36)	0.035	ND	ND	5	7	>13[6]	Sites 150 m apart
Lishoen Estates, Kalamalka Lake	30/07/80	0.2 (4 sites)	45	4 (55)	0.016	ND	ND	<1	1	14	4 sites along 1100 m shoreline
S. End Kalamalka Lake	25/09/80	1.52 (6 sites)	45	3 (42)	0.31	4-7	11-14	14-21	14-21	25-28	6 sites along 3.6 km shoreline; first sampled 4 days after treatment; suspect stations affected by drift from 8.5 ha treatment at N. end Wood Lake on 27/09/80

TABLE 2 (Continued)

Location	Application Date	Treatment Size (ha)[1]	Treatment Rate (kg a.i./ha)	No. Sampling Stations & (No. Samples)	Maximum[2] 2,4-D Conc.	Persistence in Days[3] per Conc. in mg/L >0.1	>0.05	>0.01	>0.005	>0.001	Comments
B. Treatments larger than 1 ha in open water, listed by treatment size											
S. End Wood Lake	08/06/79	5.9	22/45	4 (65)	0.027	ND	ND	21-24	41-46[7]	107	First sampled 9 days aftet treatment
N. End Kalamalka Lake	14/06/79	11.5	22/45	3 (72)	0.038	ND	ND	20	25	25	First sampled 5 days after treatment
C. Treatments in enclosed water bodies, listed by treatment date											
Walshe's Pond, Kalamalka Lake	01/08/79	0.20	22	1 (9)	1.22	61-77	61-77	>77	>77	>77	First sampled 12 days after treatment
S. End Wood Lake	10/09/80	10.0	45	4 (116)	0.62	1-4	1-4	43-47	47-50	50-55	Conc. increased after 27/09/80 treatment at N. End Wood Lake; conc. in both areas was not detectable after fall turnover of lake water column
N. End Wood Lake	27/09/80	8.5	45	4 (45)	0.015	ND	ND	26-30	30-33	30-38	First sampled 5 days after treatment

ND = not detected at this concentration

[1] Where several adjacent sites were treated, total area of all sites combined is given.

[2] Treatment areas were first sampled on treatment day (approx. 6 hrs after treatment) and 1 day after treatment unless noted otherwise in comments. Maximum 2,4-D conc. are not comparable for sites first sampled 2 days or more after treatment as the highest conc. often occurred on the first day following treatment.

[3] Persistence is given as the last day when herbicide in water samples at any station was greater than specified concentrations. Persistance is shown as a range where time between sample dates >1 day.

[4] A sample with 2,4-D conc. of 0.012 mg/L collected on day 29 at Cosens Bay site 11/07/79 was anomalous.

[5] A sample with 2,4-D conc. of 0.016 mg/L collected on day 17 at Cosens Bay site 26/06/80 was anomalous.

[6] 2,4-D may have persisted a few days longer at concentrations <0.005 mg/L as no samples were taken after day 13 following the 09/09/80 Coldstream Ck. treatment.

[7] A sample with 2,4-D conc. of 0.007 mg/L collected on day 96 at the S. end Wood Lake site 08/06/79 was anomalous.

TABLE 3
DRIFT OF 2,4-D ACID FROM HERBICIDE TREATMENTS, 1979-1980
(DRIFT ESTIMATED FROM ANALYSES OF WATER SAMPLES COLLECTED IN SAMPLE GRID IN DIRECTION OF ANTICIPATED WATER MOVEMENT FROM TREATMENT AREAS)

Location	Application Date	Treatment Size (ha)[1]	Treatment Rate (kg a.i./ha)	No. Sampling Stations & (No. Samples)	Drift at Conc. >0.05 mg/L Max. Distance (m)	Drift at Conc. >0.05 mg/L Days[2] >50 m	Drift at Conc. >0.01 mg/L Max. Distance (m)	Drift at Conc. >0.01 mg/L Days[2] >50 m	Drift at Conc. >0.001 mg/L Max. Distance (m)	Drift at Conc. >0.001 mg/L Days[2] >50 m	Comments
A. Treatments smaller than 1 ha in open water, listed by treatment date											
Cosens Bay, Kalamalka Lake	26/06/80	0.50 (6 sites)	45	2 (23)	ND	-	ND	-	460	20	Stations at 90 and 460 m from sites[3]
Coldstream Ck. Kalamalka Lake	09/09/80	1.0 (2 sites)	45	4 (72)	ND	-	ND	-	425	2	Stations 190, 425 and 610 m from sites[3]
Lisheen Estates Kalamalka Lake	30/07/80	0.2 (4 sites)	45	5 (64)	ND	-	ND	-	100	7	Stations 100-600 m from sites
S. End Kalamalka Lake	25/09/80	1.52 (6 sites)	45	6 (45)	ND	-	ND	-	1100	4-7	Stations 1100-2100 m from sites; suspect drift through Oyama Canal from 8.5 ha treatment at N. end Wood Lake on 27/09/80

Location	Application Date	Treatment Size (ha)[1]	Treatment Rate (kg a.i./ha)	No. Sampling Stations & (No. Samples)	Drift at Conc. >0.05 mg/L Max. Distance (m)	Drift at Conc. >0.05 mg/L Days[2] >500 m	Drift at Conc. >0.01 mg/L Max. Distance (m)	Drift at Conc. >0.01 mg/L Days[2] >1000 m	Drift at Conc. >0.01 mg/L Days[2] >500 m	Drift at Conc. >0.001 mg/L Max. Distance (m)	Drift at Conc. >0.001 mg/L Days[2] >1000 m	Drift at Conc. >0.001 mg/L Days[2] >500 m	Comments
B. Treatments larger than 1 ha in open water, listed by treatment size													
S. End Wood Lake	08/06/79	5.9	22/45	15 (78)	ND	-	2000	3	3	2000	3	3	Stations 500-7300 m from site; stations beyond 2000 m added after day 4[3]
N. End Kalamalka Lake	14/06/79	11.5	22/45	9 (108)	ND	-	1000	1	NS	1000	2	NS	Stations 1000-4200 m from site

TABLE 3 (Continued)

Location	Application Date	Treatment Size (ha)[1]	Treatment Rate (kg a.i./ha)	No. Sampling Stations & (No. Samples)	Drift at Conc. >0.05 mg/L Max. Distance (m)	Drift at Conc. >0.05 mg/L Days[2] >500 m	Drift at Conc. >0.01 mg/L Max. Distance (m)	Drift at Conc. >0.01 mg/L Days[2] >1000 m	Drift at Conc. >0.01 mg/L Days[2] >500 m	Drift at Conc. >0.001 mg/L Max. Distance (m)	Drift at Conc. >0.001 mg/L Days[2] >1000 m	Drift at Conc. >0.001 mg/L Days[2] >500 m	Comments
C. Treatments in areas where dispersion restricted by lake size													
S. End Wood Lake	10/09/80	10.0	45	23 (142)	ND	-	ND	-	-	6000	>14	>14	Stations 500-6000 m from sites[5]; most of the 930 ha lake epilimnion had 2,4-D conc. of 0.001-0.003 mg/L just before 8.5 ha treatment at north end on 27/09/80 which increased epilimnion conc. at all drift stations to max. of 0.0095 mg/L until lake turnover about 28/10/80
N. End Wood Lake	27/09/80	8.5	45	5 (86)	ND	-	ND	-	-	6000	30-33	30-33	

Note: Herbicide residue samples taken closer than 10 m to treatment site not considered.

ND = not detected; NS = not sampled

1 Where several sites were treated, total area of all sites combined is given.

2 Persistence is given as the last day when herbicide concentrations in water samples were greater than specified concentrations. All samples taken on the next day were below the specified concentrations. Persistence is shown as a range where time between samples dates >1 day.

3 At these treatment sites, an increase in the size of the sample station grid within <1 day to 2 days after treatment may have resulted in detection of herbicide further than the maximum recorded.

4 Drift stations were located along entire length of Wood Lake (6000 m) for treatments on 10/09/80 and 27/09/80.

TABLE 4
CHANGE IN ABUNDANCE OF M. SPICATUM FOLLOWING 2,4-D TREATMENTS[1]

Lake	Location	Treatment Date	Size (ha)	Effectiveness
A. 1979 Treatments				
Kalamalka Lake	North End	14/06/79	11.5	90% decline
		21/06/79	0.42 (2 sites)	
	Cosens Bay	11/07/79		
		01/08/79	0.8 (7 sites)	20% decline
		12/09/79		
	Walshe's Pond	01/08/79	0.2	100% decline
Wood Lake	South End	08/06/79	5.9	10% expansion
		21/06/79	0.7 (3 sites)	
B. 1980 Treatments				
Kalamalka Lake	North End	09/09/80	1.0 (2 sites)	1100% expansion
	Cosens Bay	11/07/80	0.4 (6 sites)	60% decline
	Lisheen Estates	30/07/80	0.2 (4 sites)	20% decline
	South End	25/09/80	1.56 (6 sites)	40% expansion
Wood Lake	South End	10/09/80	10.0	10% expansion
	North End	27/09/80	8.5	30% expansion

[1] Method of calculation described in Appendix II.

APPENDIX I

2,4-D CONCENTRATIONS IN SEDIMENT SAMPLES FROM KALAMALKA AND WOOD LAKES, 1979 AND 1980

TABLE 1

CONCENTRATIONS OF 2,4-D (ug/g) IN SEDIMENT, SOUTH END OF WOOD LAKE, TREATED ON JUNE 8, 1979

Station No.[1]	Analysis	Sample Dates and Days After Treatment							
		June 15 Day 7	June 25 Day 17	June 28 Day 20	July 6 Day 28	July 12 Day 34	July 19 Day 41	Aug. 20 Day 72	Sept. 20 Day 104
A. Treatment Area Stations									
11222-27	Acid	-	-	-	<0.005	<0.005	<0.005	<0.005	-
	Acid	-	-	-	0.17	<0.005	<0.005	<0.005	-
	Acid	-	-	-	-	-	-	<0.005	-
	Acid	-	-	-	-	-	-	<0.005	-
11222-28	Acid	0.061	1.61	0.072	-	-	-	-	-
	Acid	0.092	0.124	0.400	-	-	-	-	-
	Acid	-	0.1	-	-	-	-	-	-
11222-30	Acid	0.132	0.029	1.500	<0.005	<0.005	0.033	<0.005	<0.005
	Acid	0.098	0.036	0.26	0.013	<0.005	1.02	<0.005	<0.005
	Acid	-	0.01	-	-	-	-	-	-
Mean Conc.	Acid	0.096	0.322	0.558	<0.048	<0.005	<0.266	<0.005	<0.005
B. Stations Outside Treatment Area									
11222-31	Acid	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
	Acid	-	-	0.005	-	-	-	-	
11222-33	Acid	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
		-	-	0.005	-	-	-	-	
Mean Conc.	Acid	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	

[1] Stations located on Figure 5.

TABLE 2
CONCENTRATIONS OF 2,4-D (µg/g) IN SEDIMENT, COSENS BAY, KALAMALKA LAKE, TREATED ON JUNE 26, 1980

Station No.[1]	Analysis	Sample Dates and Days Before/After Treatment		
		June 24 Day -2	Aug. 1 Day 36	Aug. 22 Day 57
A. Treatment Area Stations				
11222-50	Acid	<0.005	0.005	0.29
11222-51	Acid	<0.005	0.21	0.02
11222-52	Acid	<0.005	<0.005	0.35
11222-53	Acid	<0.005	1.39	<0.005
Mean Conc.	Acid	<0.005	<0.403	<0.166
B. Stations Outside Treatment Area				
11222-54	Acid	<0.013[2]	<0.005	<0.005

[1] Stations located on Figure 6.

[2] Indicated pre-treatment presence of 2,4-D or analysis error.

TABLE 3

CONCENTRATIONS OF 2,4-D (µg/g) IN SEDIMENT, LISHEEN ESTATES, KALAMALKA LAKE, TREATED ON JULY 30, 1980

Station No.[1]	Analysis	Sample Date and Days After Treatment Aug. 12 Day 13
11222-62	Acid	0.08
11222-63	Acid	0.008
11222-64	Acid	0.069
11222-65	Acid	0.067
Mean Conc.	Acid	0.056

[1] Stations located on Figure 6.

TABLE 4

CONCENTRATIONS OF 2,4-D (µg/g) IN SEDIMENT, SOUTH END OF KALAMALKA LAKE, TREATED ON SEPTEMBER 25, 1980

Station No.[1]	Analysis	Sample Date and Days After Treatment: Nov. 19 Day 53
11222-39	Acid	0.36
	Acid	0.068
	BEE	<0.005
	BEE	<0.005
Mean Conc.	Acid	0.052
Mean Conc.	BEE	<0.005

[1] Stations located on Figure 7.

TABLE 5

CONCENTRATIONS OF 2,4-D (µg/g) IN SEDIMENT, SOUTH END OF WOOD LAKE, TREATED ON SEPTEMBER 10, 1980

Station No.[1]	Analysis	Sample Dates and Days Before/After Treatment		
		Sept. 9 Day -1	Nov. 19 Day 70	Mar. 26 Day 197
11223-04	Acid	<0.005	0.1	-
	Acid	<0.005	0.082	-
	BEE	-	0.008	-
	BEE	-	<0.005	-
11223-05	Acid	<0.005	0.64	-
	Acid	<0.005	1.5	-
	BEE	-	0.014	-
	BEE	-	0.026	-
11223-06	Acid	-	-	0.37
	Acid	-	-	0.41
	Acid	-	-	0.39
11223-07	Acid	-	-	0.125
	Acid	-	-	0.22
	Acid	-	-	0.11
Mean Conc.	Acid	<0.005	0.581	0.271
Mean Conc.	BEE	-	0.013	-

[1] Stations located on Figure 8.

TABLE 6

CONCENTRATIONS OF 2,4-D (µg/g) IN SEDIMENT, NORTH END OF WOOD LAKE, TREATED ON SEPTEMBER 27, 1980

Station No.[1]	Analysis	Sample Dates and Days After Treatment	
		Nov. 19 Day 53	Mar. 26 Day 180
11223-69	Acid	0.015	0.19
	Acid	0.05	0.19
	Acid	-	0.24
	BEE	0.007	-
	BEE	0.012	-
11223-70	Acid	0.026	0.34
	Acid	0.028	0.22
	Acid		0.23
	BEE	<0.005	-
	BEE	0.009	-
Mean Conc.	Acid	0.03	0.235
Mean Conc.	BEE	<0.033	

[1] Stations located on Figure 8.

APPENDIX II

METHOD FOR CALCULATING PERCENT CHANGE IN *M. SPICATUM* ABUNDANCE FOLLOWING HERBICIDE TREATMENTS

Aquatic vegetation distribution charts were prepared for the littoral area of Kalamalka and Wood Lakes from surveys made in October, 1978, October, 1979 and October, 1981. The charts indicated the location and boundaries of M. spicatum populations and the percent of the bottom covered by M. spicatum in each population. Air photographs and distance measurements in the field were used to map population boundaries and percent cover was subjectively estimated in broad categories: sparse (<1 to 33% cover); moderate (34 to 66% cover) and dense (67 to 100% cover). The "abundance" of M. spicatum in a specific population was calculated from the area within the population boundaries multiplied by the percent of bottom covered by the plant.

Effectiveness of herbicide treatment of specific populations was calculated as the percent difference in abundance of M. spicatum before and after treatments. Effectiveness of 1979 treatments was based on abundance measured from the maps made in October 1978 and October 1979 while effectiveness of 1980 treatments was based on abundance measured from maps made in October 1979 and October 1981. Most of the herbicide treatments made in 1980 were too late in the summer to conduct surveys to assess regrowth during that same year (i.e., little regrowth would have occurred in the remainder of the growing season) hence observations were made in 1981. It should be noted therefore that effectiveness of the 1979 and 1980 treatments are not directly comparable.

POOR

QUALITY

ORIGINAL